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THE EFFECTS OF ENHANCED DISPARITY ON MANUAL CONTROL

Stereopsis and Tracking Performance

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Subjects' interpupillary distance was artificially increased to 8", 12" and 26" by a stereoviewer. Subjects performed a tracking task at each setting as well as under monocular conditions. A significant improvement in performance as measured by RMS error was found when stereo information was available rather than when it was absent. The greatest improvements tended to occur at the maximum ocular separation.

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ABSTRACT

Subjects' interpupillary distances were artificially increased to 8", 12", and 26" by a stereoviewer. Subjects performed a tracking task at each setting as well as under monocular conditions. A significant improvement in performance, as measured by the RMS error, was found when stereoscopic information was available. The greatest improvement tended to occur at the maximum ocular separation.

INTRODUCTION

Background

At distances beyond 100 meters, the human's ability to utilize binocular information (stereopsis) from the position or orientation of an object in space is drastically reduced.[1] Instead, monocular cues to depth dominate our interpretation of an object's attitude in space. However, these monocular cues are not always sufficient to resolve ambiguities that can arise from this loss of useful stereopsis. The Necker cube is a familiar example of a monocular cue resulting in ambiguous depth perception.[2]

More important than exotic perceptual illusions, such ambiguities can have deleterious effects on the reaction time and decisions that are needed for optimal performance of a visual-motor task, i.e. flying. When the correct actions depend on knowing the object's changing attitude, such reactions may be delayed until the ambiguity is resolved. This ambiguity can be eliminated in most cases by the introduction of non-ambiguous binocular disparity information about the object. Such information would reduce reaction times from those using only monocular cues to depth.

Factors that limit the distance (E) at which disparity information about an object can be processed are interpupillary distance (a), stereo-acuity of the subject (n), and the depth interval spanned by the object (d). The relationship of these parameters is shown in Equation I.[3]

$$E^2 = ad/n \qquad \text{(Equation 1)}$$

This equation shows that for a given depth interval (d), the useful distance for stereopsis can be increased if the stereoacuity of the subject is lowered or the interpupillary distance is increased. The stereoacuity limit in the human is fixed by the neurophysiology of the nervous system,[1] but the interpupillary distance can be increased optically or electronically. This increased interpupillary distance was one of the methods used by aerial reconnaissance teams to detect camouflaged objects on the ground. By taking photographs of the same area from several hundred feet apart and then viewing them stereoscopically, the hidden areas became visible by virtue of their three-dimensionality.

With the advent of helmet mounted displays,[4] where two channels of visual information can be presented to the subject, there now exists the ability to present normal as well as enhanced disparity images for use in flight operations and simulators. In aircraft applications, two image sensors placed several feet apart, with each sensor relaying information exclusively to one side of the dual channel display system, would enable a pilot to utilize disparity information from objects at distances several orders of magnitude beyond the normal useful range of stereopsis. Such information would be useful in early detection of attitude changes of aircraft, beyond the normal range of stereopsis where monocular cues could not resolve the ambiguity. Other applications include air refueling, especially at night when depth cues are greatly reduced by low lighting conditions[5] and in acquisition of camouflaged ground targets by weapons officers.

However, before such systems can be used for these and other purposes, more information on the effects of enhanced disparity images on performance and depth judgement is needed. This report deals with the role of enhanced disparity in human tracking of objects moving in depth. The results show that using stereovision causes a dramatic improvement in performance over monocular cues to depth, with the best performance at the largest optical separation of the eyes.

METHODS

The subject's task was to minimize or null target disturbances in the longtiudinal direction from a position between two fixed targets. The subject viewed three targets through a variable baseline stereoscope placed 60 feet away from the targets (Figure 1). The center target was movable with the fixed targets spaced 1" on either side. The signals to the central target were a combination of a sum of five sinusoids and joystick control commands from the subjects. As the center target was disturbed from its position between the two fixed targets, the subject would null this motion by pushing the joystick forward to return a too near target or pulling back on the stick to return a too distant target. In this fashion, the subject attempted to minimize the target's movement between the two fixed targets. Subjects performed 20 to 27 trials, each trial lasting 26 seconds, under each viewing condition. At the conclusion of each viewing condition, the subjects rested for seven minutes before starting again.

Changes in interpupillary distance (IPD) were effected by a Bausch and Lomb Stereoviewer stereoscope that could change its baseline separations from 8" to 26". IPD values of 8", 12" and 26" were used in these experiments, and the sequence of IPDs presented to each subject was different in order to minimize ordering effects. The stereoscope had a magnification of 5.0, a fixed vergence angle of 0°, and each channel had a field of view of 60°. To obtain monocular viewing conditions, the IPD was set at 8" and the objective of the non-dominant eye's channel was covered. Thus the subjects had both eyes open, but only one of the optical channels transmitted an image.

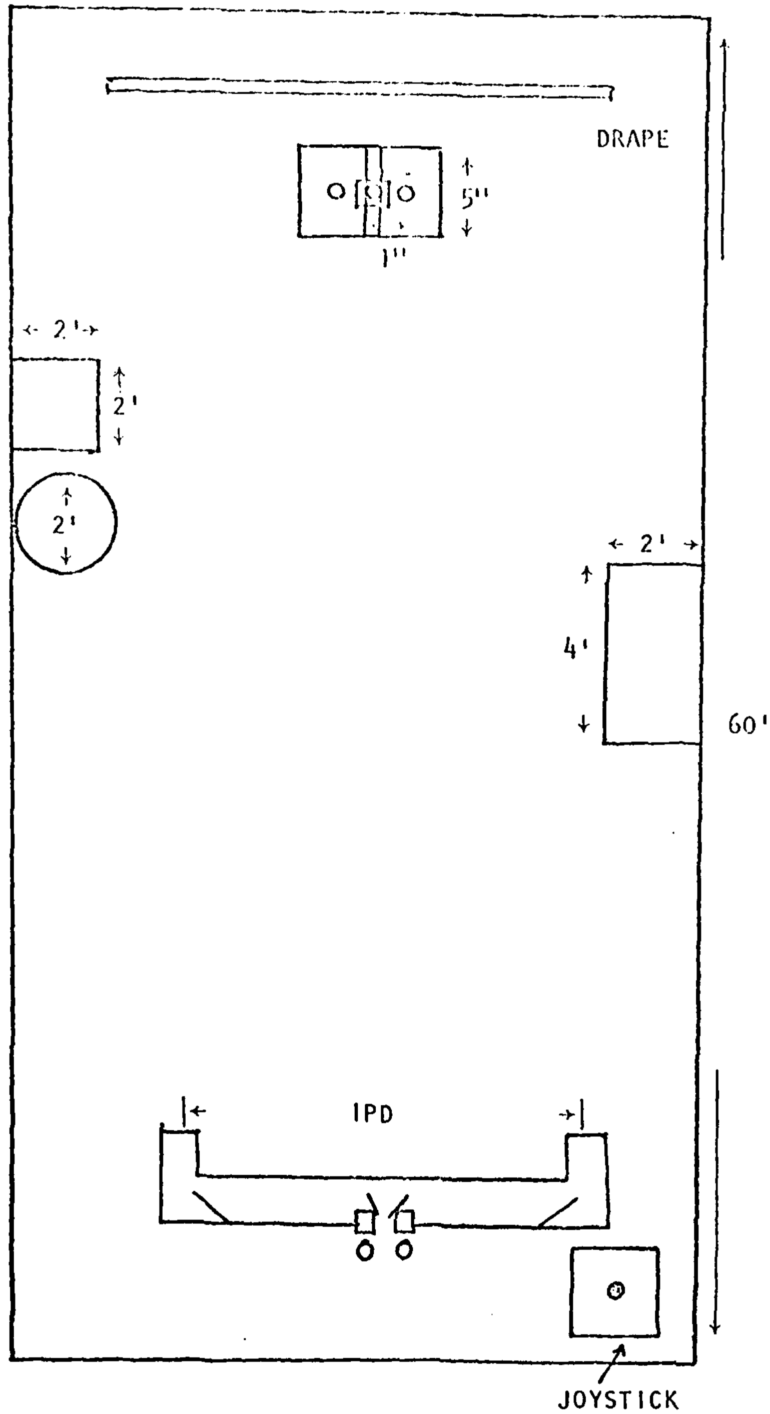

Figure 1. Diagram of the experimental set up.

The apparatus used to provide a tracking target was based on the standard three rod apparatus used to measure stereo acuities. However, unlike most three rod apparatus systems, this system did not attempt to eliminate all but stereocues to depth. While lighting was arranged so that shadows could not be used as cues, size changes and small changes in target luminance were available to the subject. The purpose of this design was to simulate as much as possible the conditions that would be available under operational situations. However, motion parallax caused by head movements was not available in this set up.

The targets were cylindrical wooden dowels with a white tip for maximum visibility. The target's dimensions measured 3 inches high and 0.16 inches in diameter, which translates to a horizontal visual angle of 12 min arc. The two outer, fixed targets were placed 1 inch from the movable center target. This separation equals 75 min arc of visual angle. The center target was moved in the longitudinal direction a maximum of ± 5 inches. The disparity produced by this displacement equalled ± 16 sec of arc for the 8 inch IPD, ± 24 sec of arc for the 12 inch IPD, and ± 52 sec of arc for the 26 inch IPD.

The targets were illuminated by an overhead fluorescent light which gave a target luminance of 0.82 log ft-lamberts (measured by an SEI photometer). The light was arranged so that shadows that could provide obvious cues to target distance and direction changes were eliminated. To enhance target detectability, a dark blue cloth was draped behind the targets. This dark background spanned ± 5° and had a luminance of 0.06 log ft-lamberts. The combined target and background resulted in a contrast of 0.86 using the formula $(\ell_{max} - \ell_{min})/(\ell_{max} + \ell_{min})$.

The subject's visual field contained objects other than the tracking stimuli. The experiment was performed in a long corridor that had doors, boxes and lighting fixtures visible to the subject. All subjects experienced the same visual environment.

The target disturbance consisted of the sum of five sinusoids of equal amplitude and random phase[6]. The frequencies used included 0.117 Hz (ϕ = 0°), 0.195 Hz (ϕ = 210°), 0.273 Hz (ϕ = 60°), 0.430 Hz (ϕ = 271°), and 0.500 Hz (ϕ = 121°). The signal disturbance contained a sufficient number of frequencies to approximate a random signal to the subject. The bandwidth of the servo controlling the center target was at least 40 Hz. A PDP 11/34 minicomputer controlled the experiment by (1) producing the disturbance signal, (2) acquiring the joystick movement from the subject (sampling rate = 40 Hz), (3) adding these two signals and using the resultant to drive the center target, and (4) storing this result on a mass storage device.

Means and standard deviations were calculated for each subject for each of the four viewing conditions in the experiment. The statistical significance of these means were examined within each subject using the t-test. Intersubject testing was not performed with this small sample size.

Three normal volunteers from the Institute participated in the study. All had experience in target nulling experiments and were in good physical condition. Visual acuities were all corrected to 20/20 or better and stereoacuities were at least 10 min of arc, measured clinically.

RESULTS

The mean RMS error was less using stereocues than without in all subjects. The means and standard deviations for each subject at each experimental condition are tabulated in Table 1 and plotted in Figure 2. These data clearly demonstrate the superior performance obtained when stereoinformation is provided in this nulling task. The mean tracking errors of all subjects when using stereopsis were significantly different than those without, at a significance level greater than 0.001, as shown in Table 2. In addition, in subjects 1 and 3 the variance of the monocular data was significantly different from the stereo condition data. Not only did RMS error increase without stereoinformation but performance varied greatly from trial to trial.

Once stereovision was provided to the subjects, improvement in performance was not realized till the maximum IPD was used. No statistical difference in performance was found between 8 and 12 inch separations in all subjects. Table 2 contains t-statistics and degrees of freedom for the interaction of all cases within subjects. In 2 subjects a statistically significant difference in performance was found between 26 and 12 or 8 inch IPD at the $p < .001$ for subject #1 and $p < .01$ for subject #2; the third subject #3 showed no such significance.

While the variation in performance within each set of stereo trials was not significantly different, in general the standard deviations were smaller at 26' than at 8 or 12 inch settings. In Figures 3-5 the RMS error vs. trials is plotted to show the changes in performance over the

TABLE 1

Subject	IPD	Mean	S. D.	N
1	0	646	±61	29
	8	543	±37	20
	12	542	±59	24
	26	490	±41	27
2	0	780	±48	25
	8	665	±71	23
	12	673	±48	26
	26	623	±39	23
3	0	654	±81	26
	8	548	±37	24
	12	543	±42	26
	26	544	±32	28

TABLE 2

Subject	IPD		IPD	t	df	p
1	0	vs	8	6.89	41	<.001
	0	vs	12	6.27	51	<.001
	0	vs	26	7.20	40	<.001
	8	vs	12	--	43	--
	8	vs	26	4.56	59	<.001
	12	vs	26	3.71	51	<.001
2	0	vs	8	6.62	46	<.001
	0	vs	12	7.96	49	<.001
	0	vs	26	12.37	47	<.001
	8	vs	12	--	48	--
	8	vs	26	2.49	34	<.01
	12	vs	26	3.97	47	<.001
3	0	vs	8	6.03	35	<.001
	0	vs	12	5.88	37	<.001
	0	vs	26	6.47	34	<.001
	8	vs	12	--	51	--
	8	vs	26	--	52	--
	12	vs	26	--	50	--

(--) = not significant

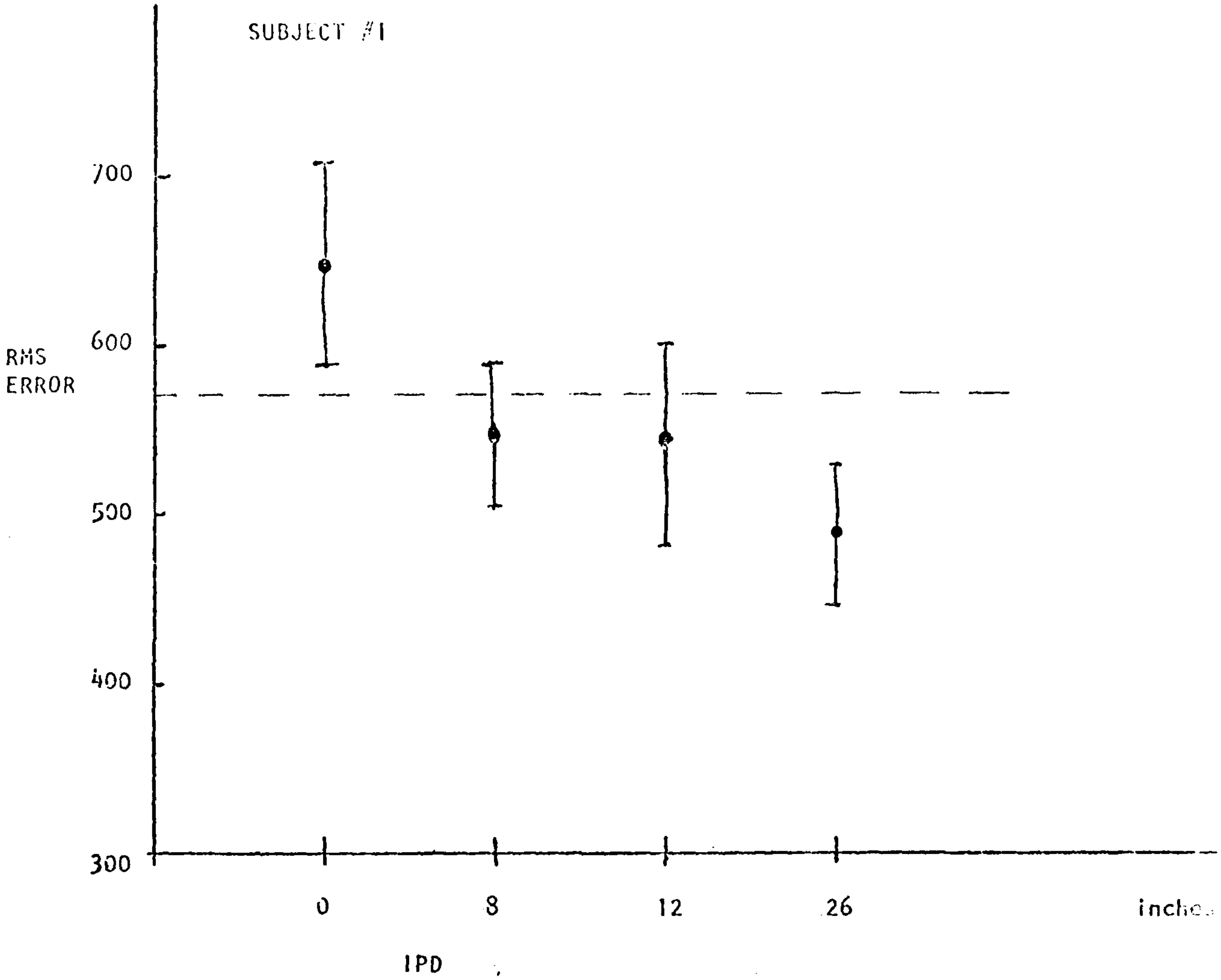

Figure 2a. Average rms error at each interpupillary distance for subject #1.

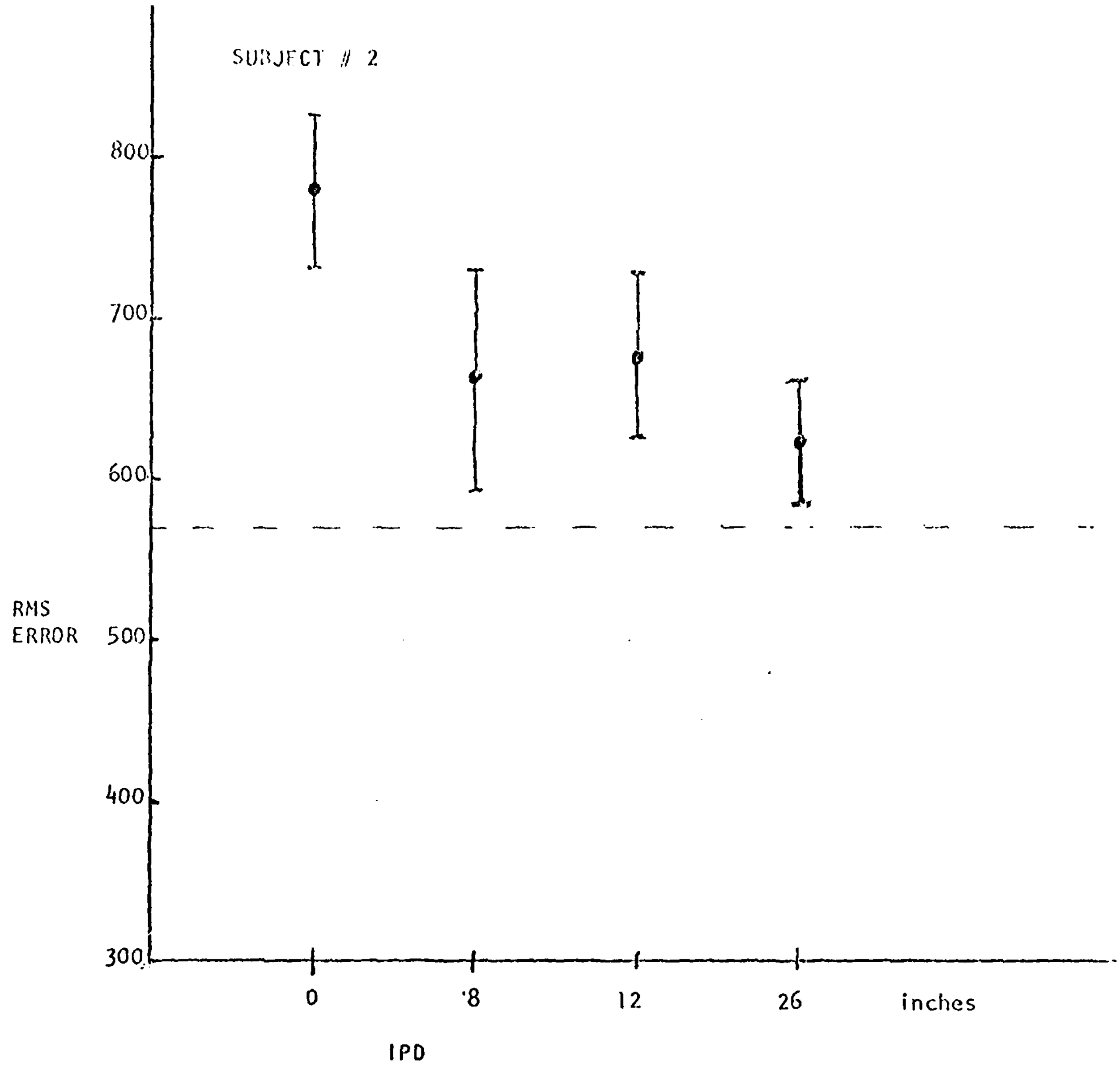

Figure 2b. Average rms error at each interpupillary distance for subject #2.

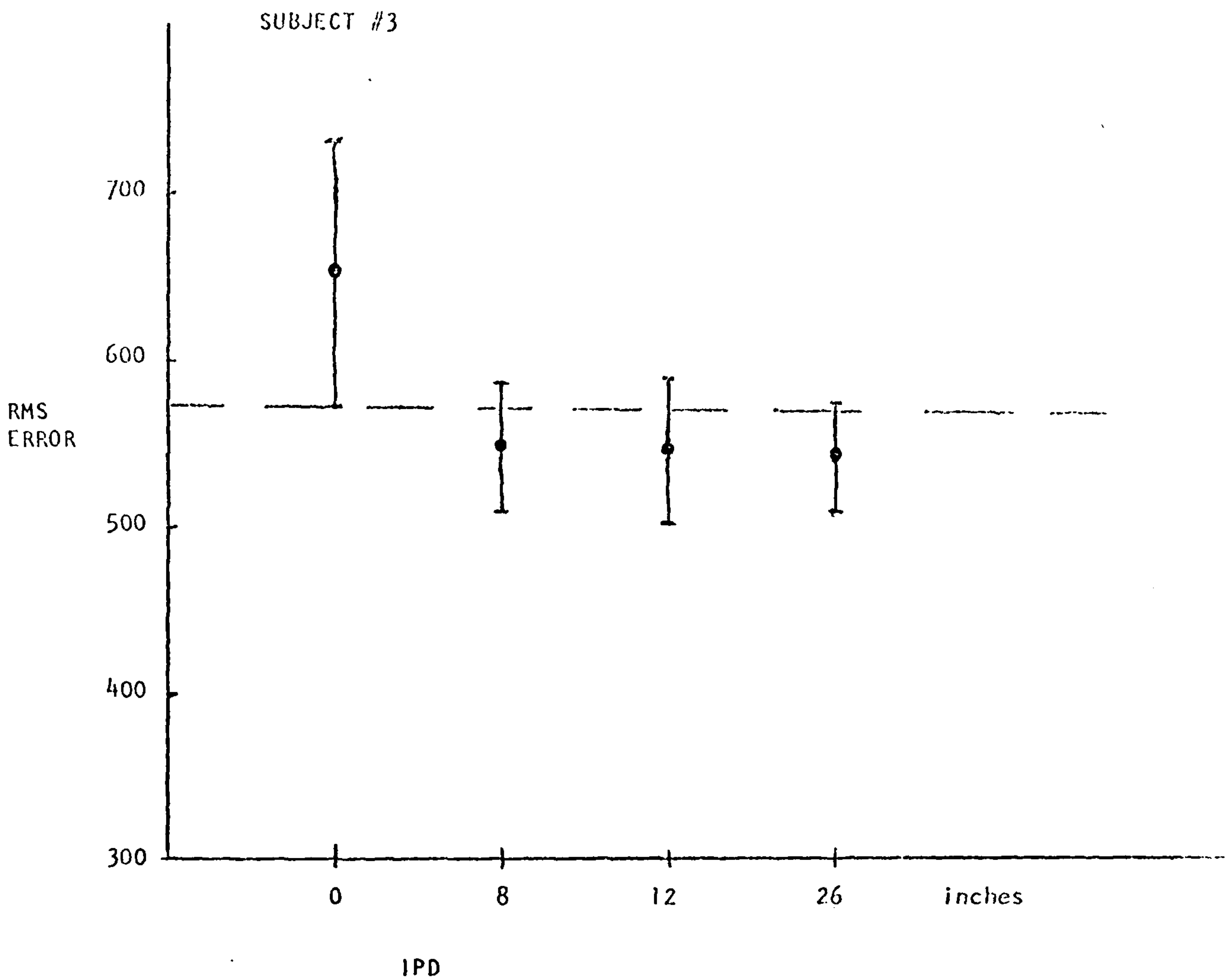

Figure 2c. Average rms error at each interpupillary distance for subject #3.

entire experiment for each subject. In subjects 2 and 3 more consistent performance is seen at 26 inches than at the other separations. For subject #1 8 inches had less variability.

Subjects did not suffer any overt physical discomforts such as eye strain, diplopia, headaches or ocular pain. However, they did note fatigue as the trials were performed. Objects in the peripheral visual field had no apparent affect on the subjects ability to fuse and track the target. Subjects reported no interference with the task from these objects. When asked about peripheral objects, subjects said they tended to ignore them and concentrate on the tracking targets.

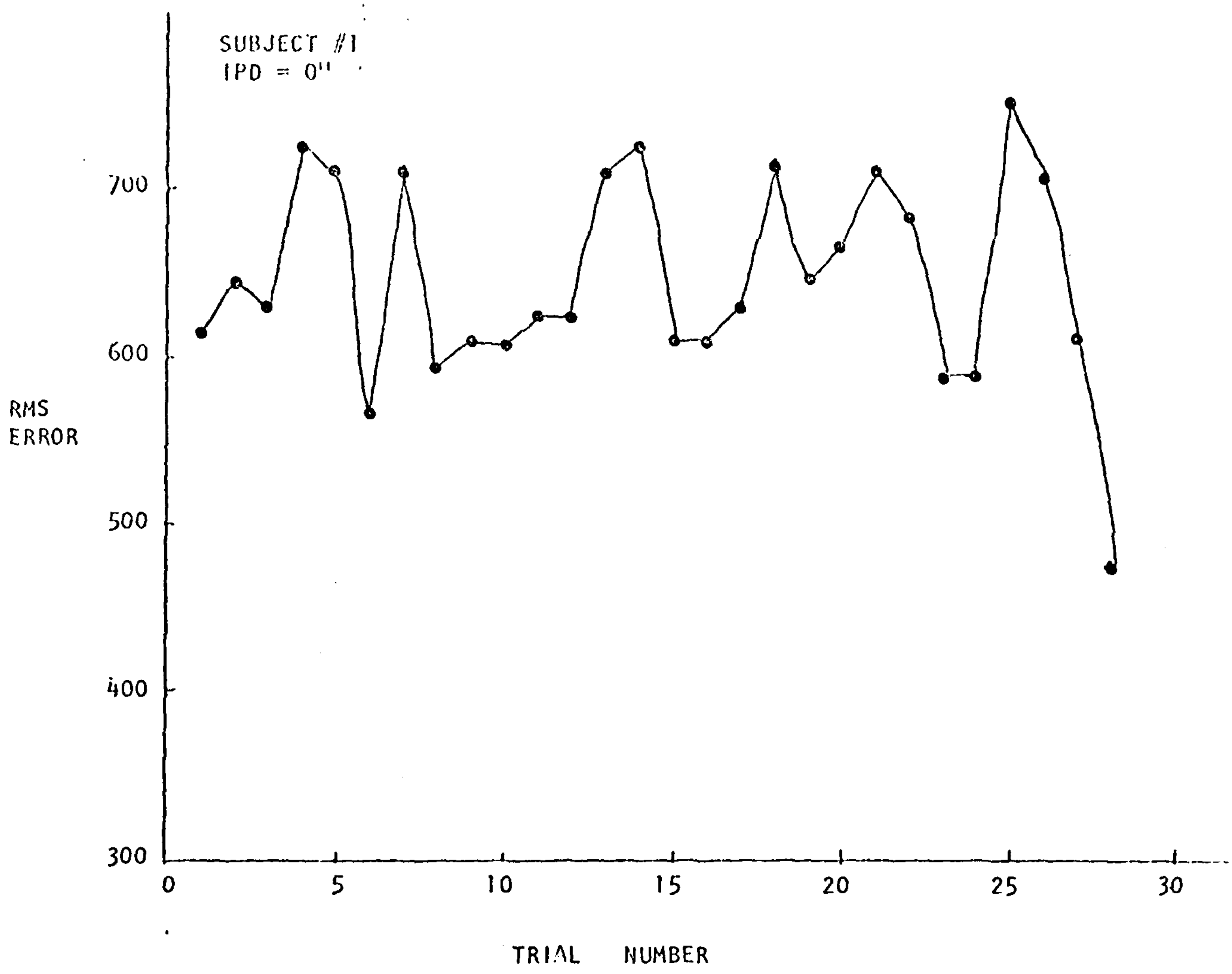

Figure 3a. Variations in rms error at given IPD

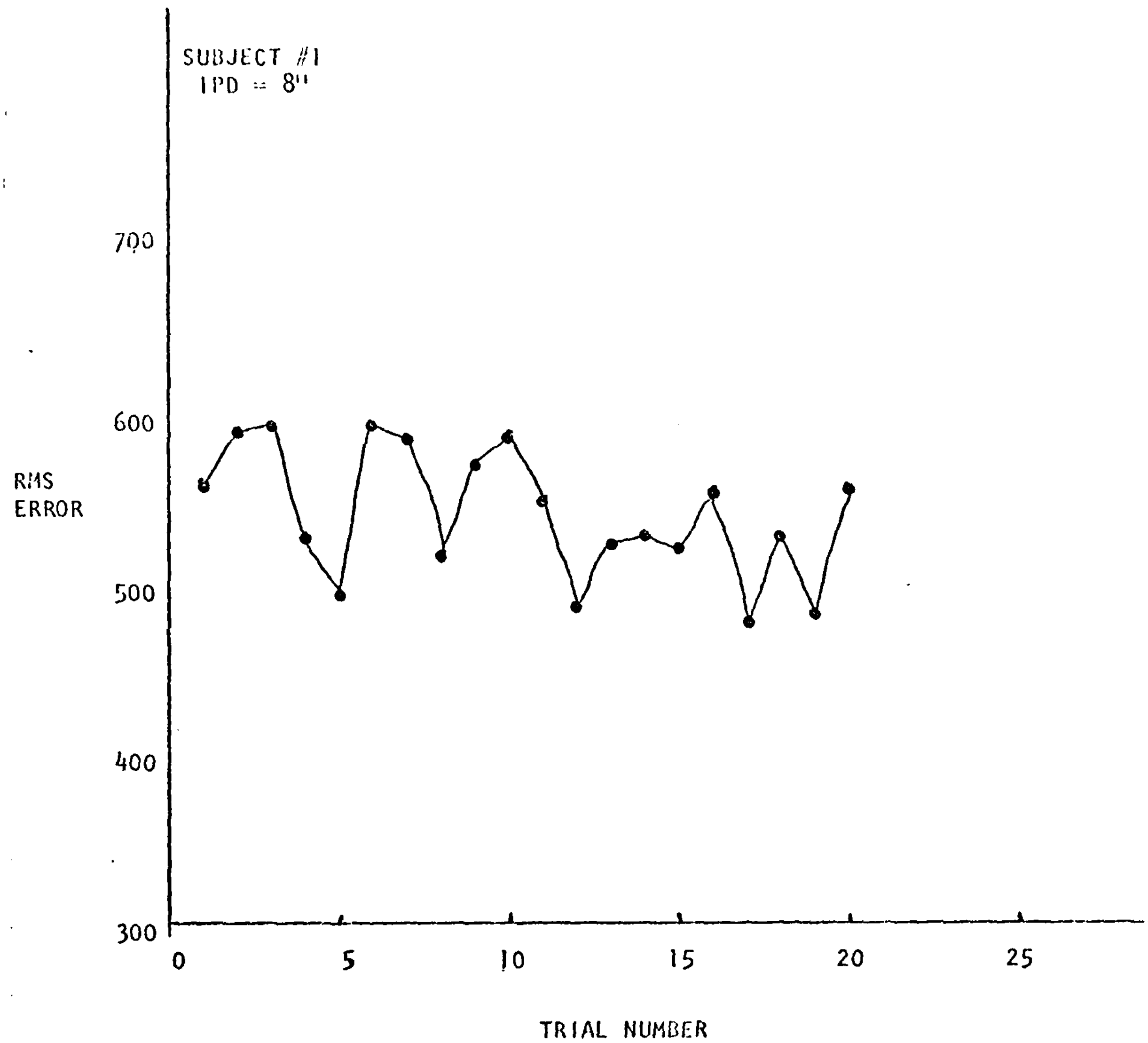

Figure 3b. Variations in rms error at given IPD

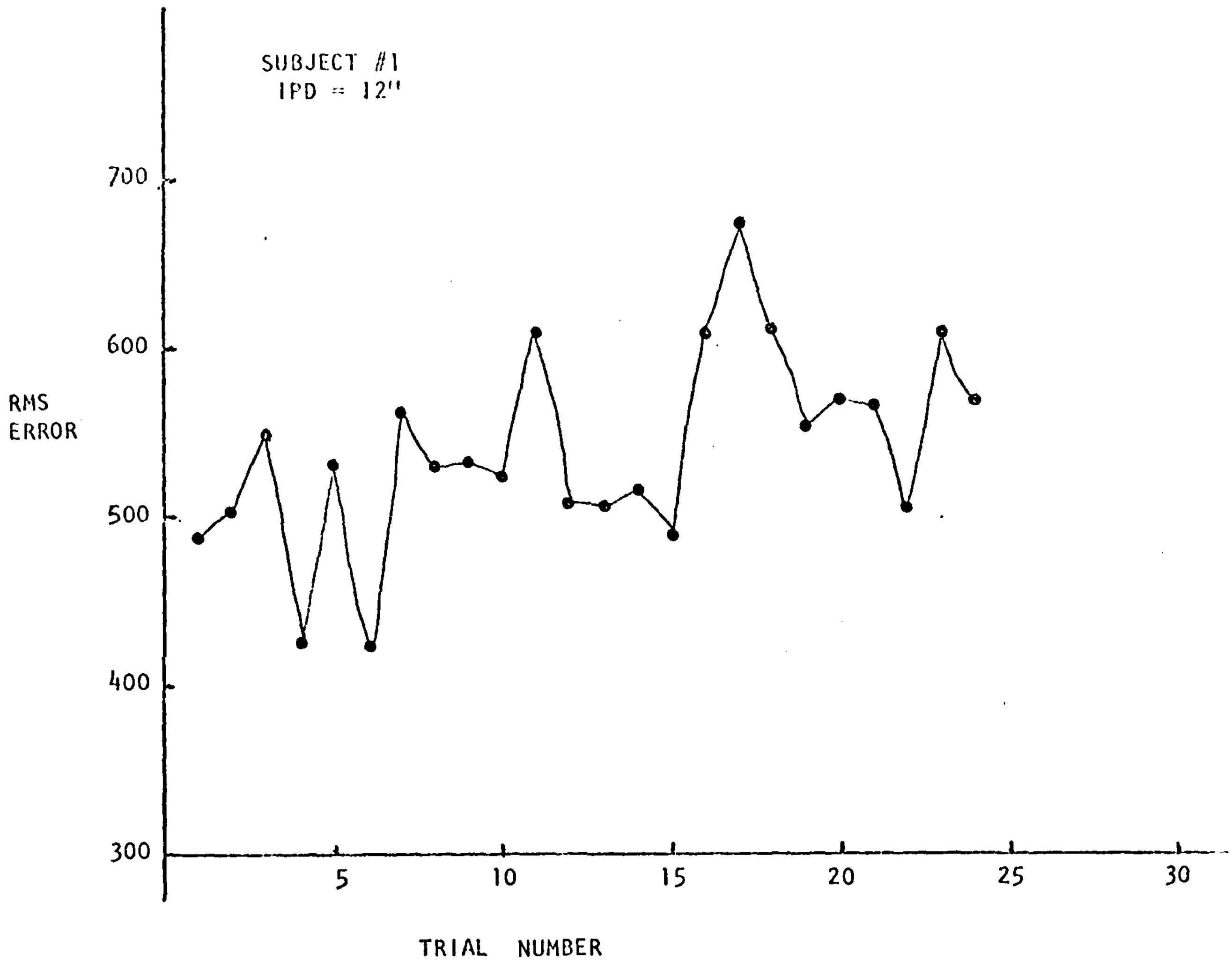

Figure 3c. Variations in rms error at given IPD

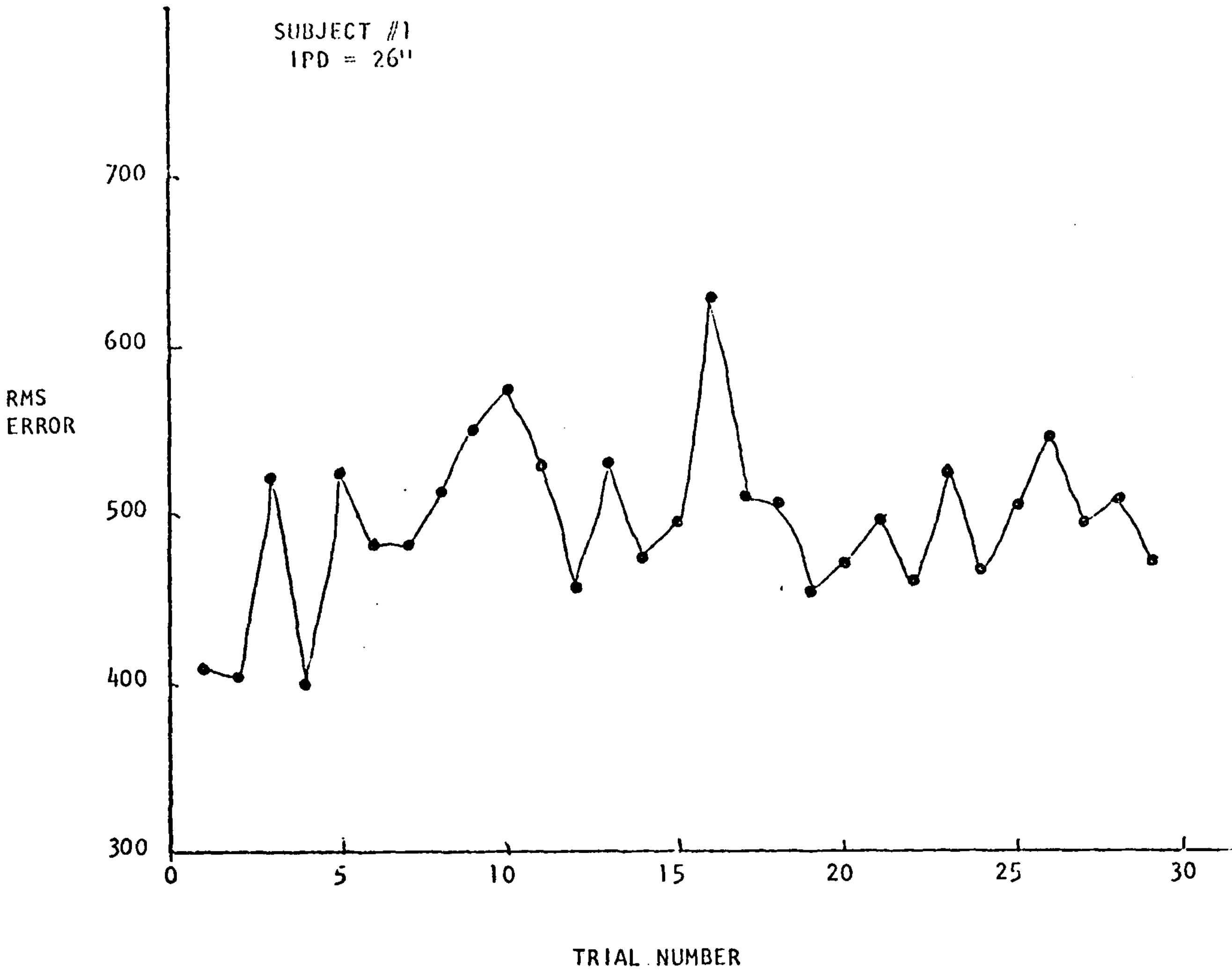

Figure 3d. Variations in rms error at given IPD

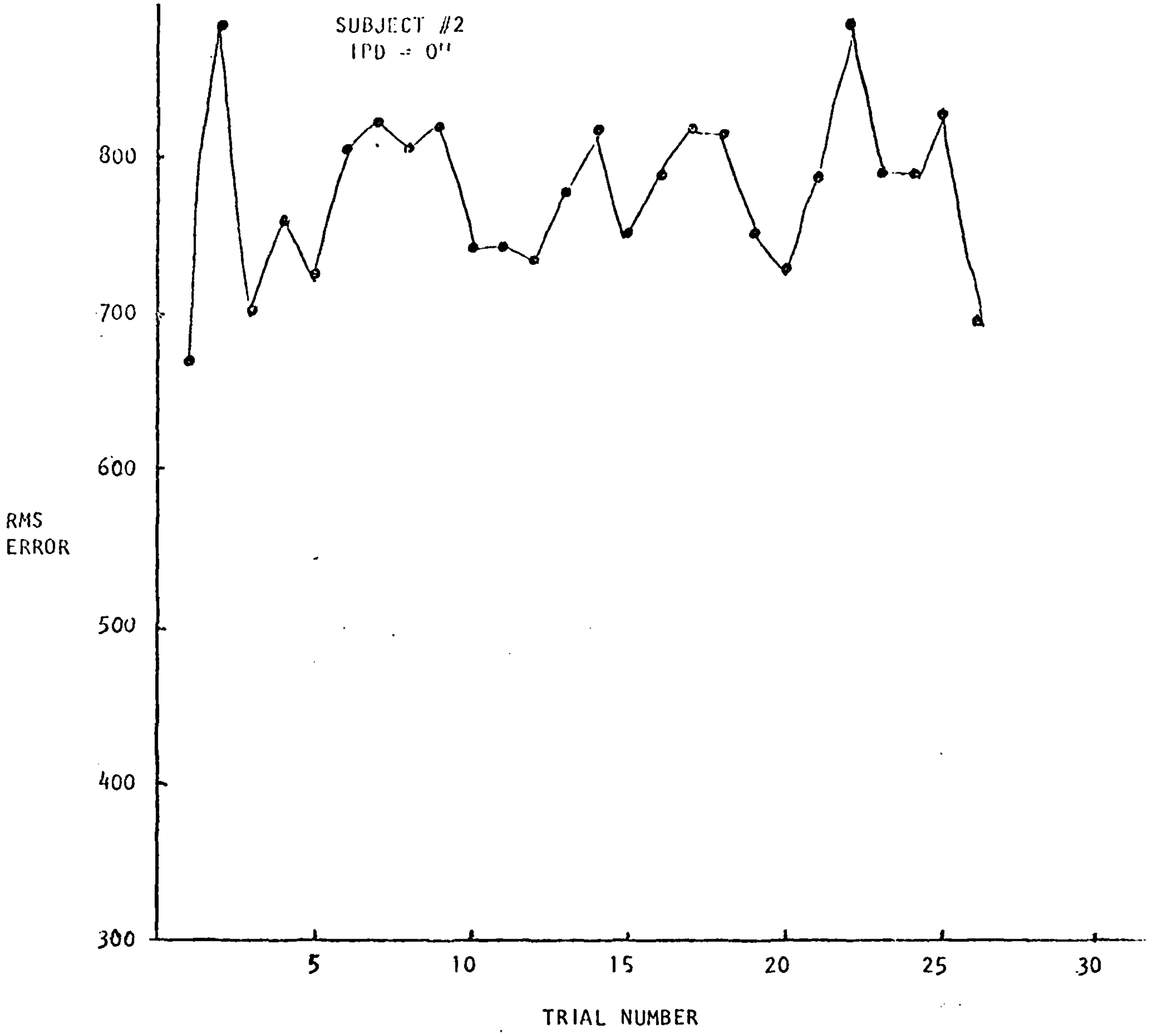

Figure 4a. Variations in rms error at given IPD

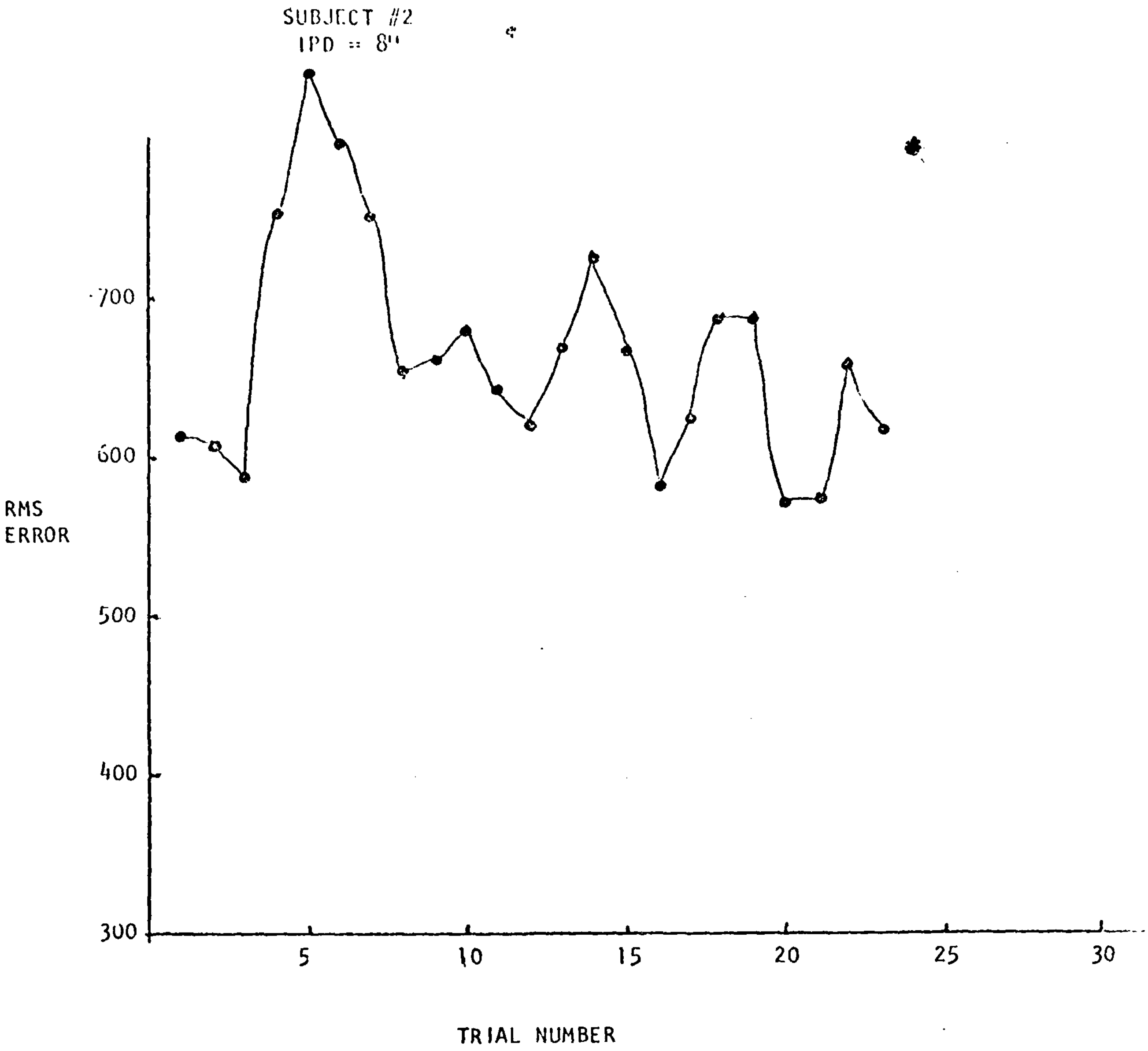

Figure 4b. Variations in rms error at given IPD

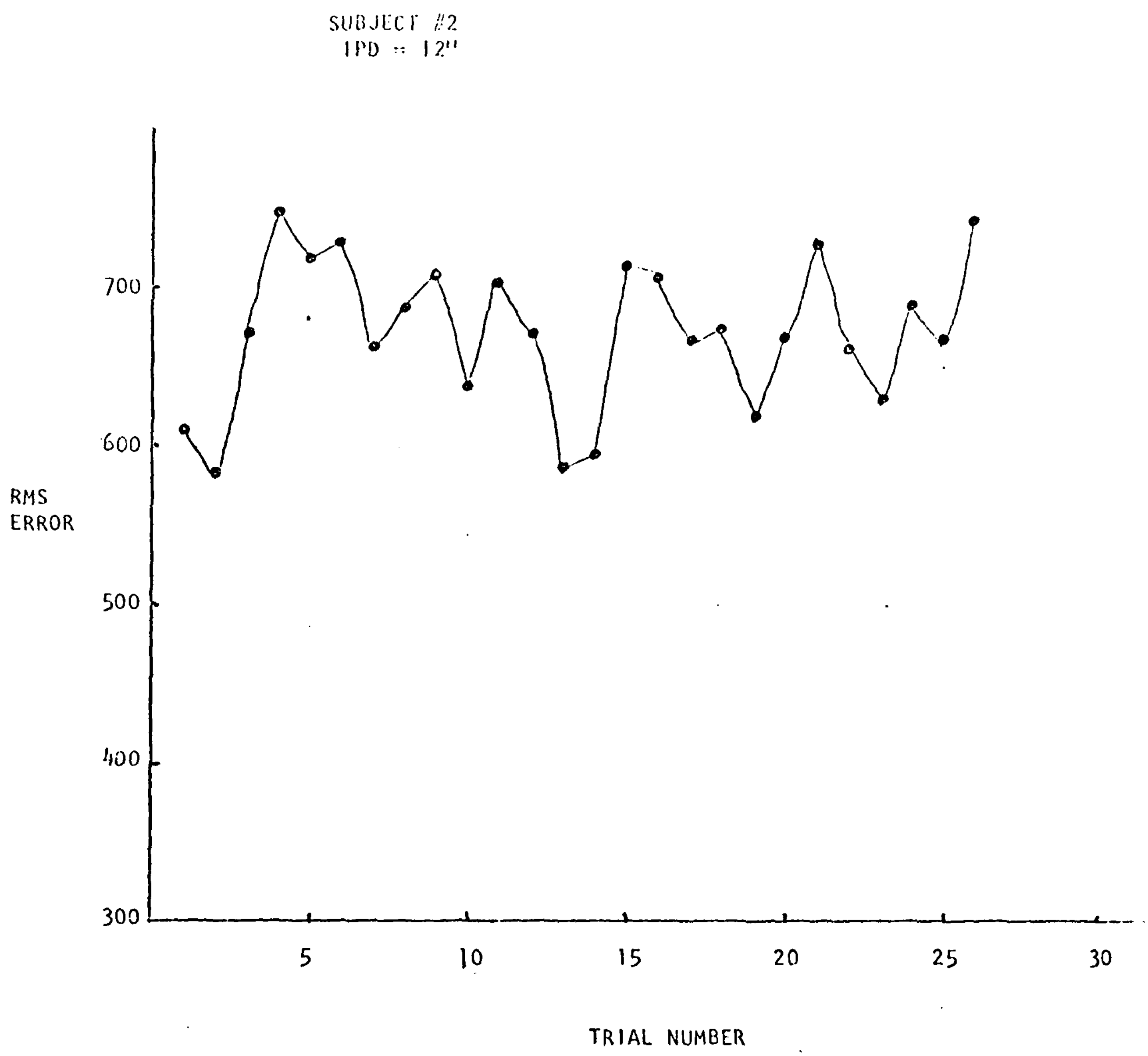

Figure 4c. Variations in rms error at given IPD

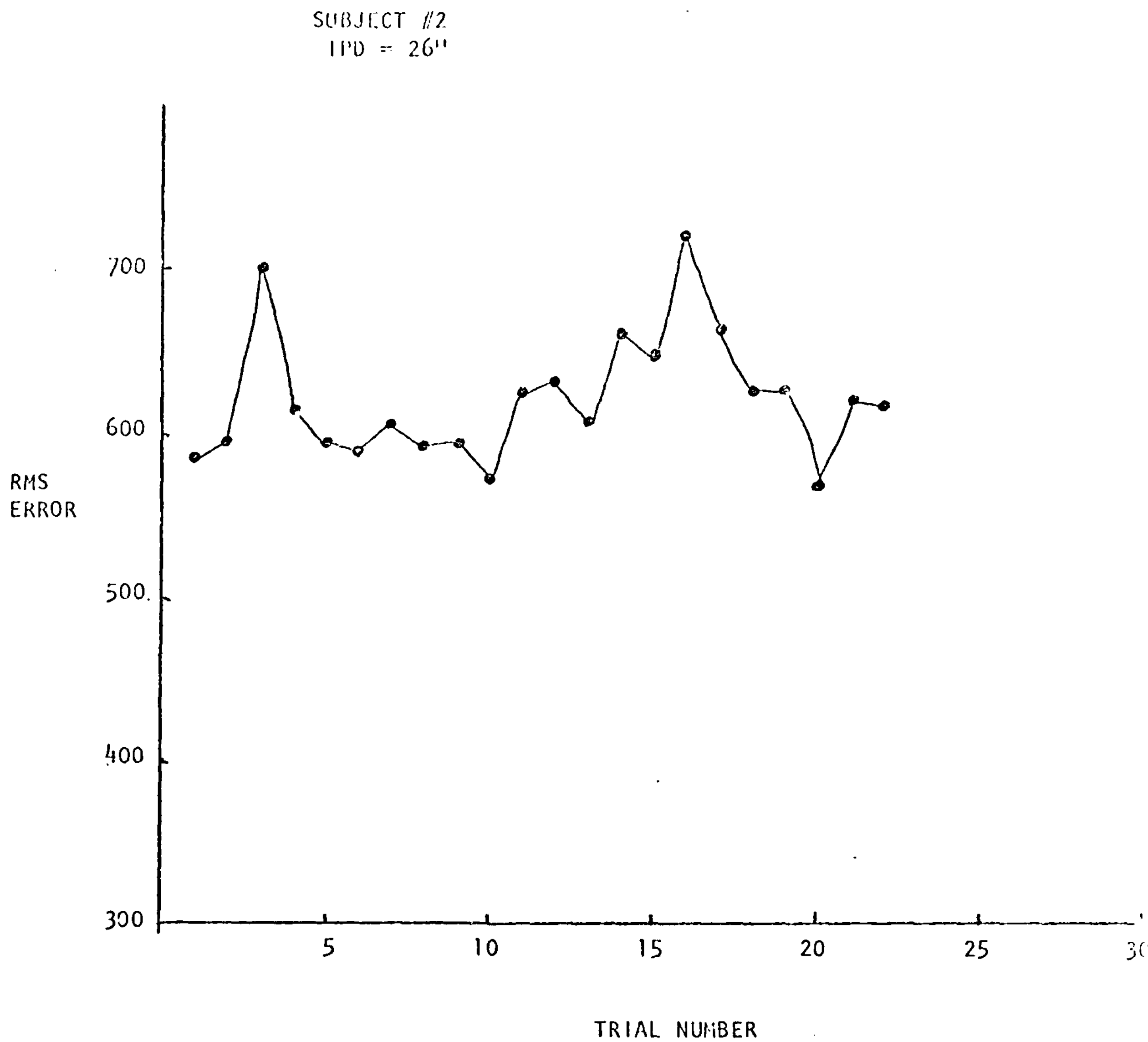

Figure 4d. Variations in rms error at given IPD

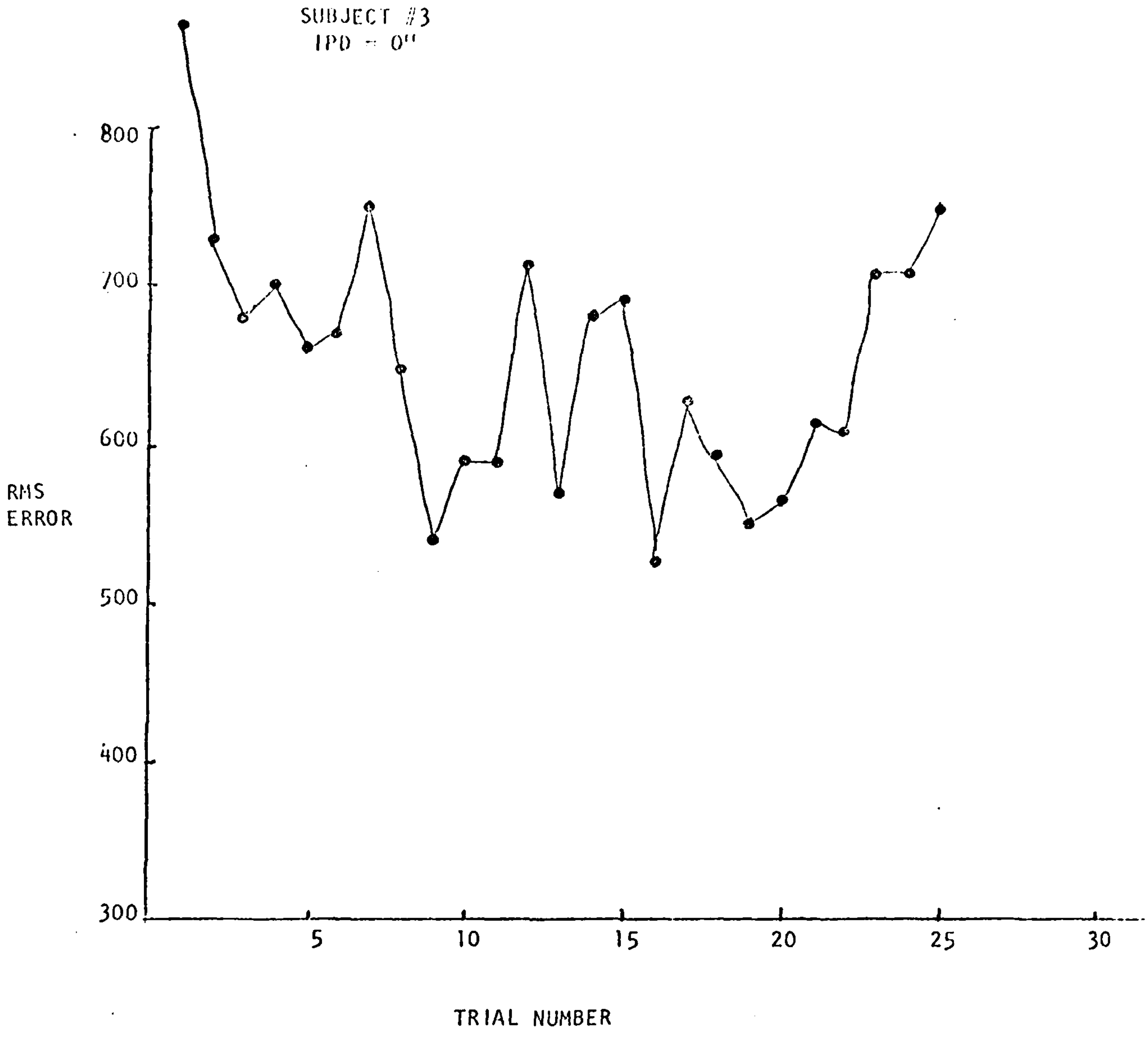

Figure 5a. Variations in rms error at given IPD

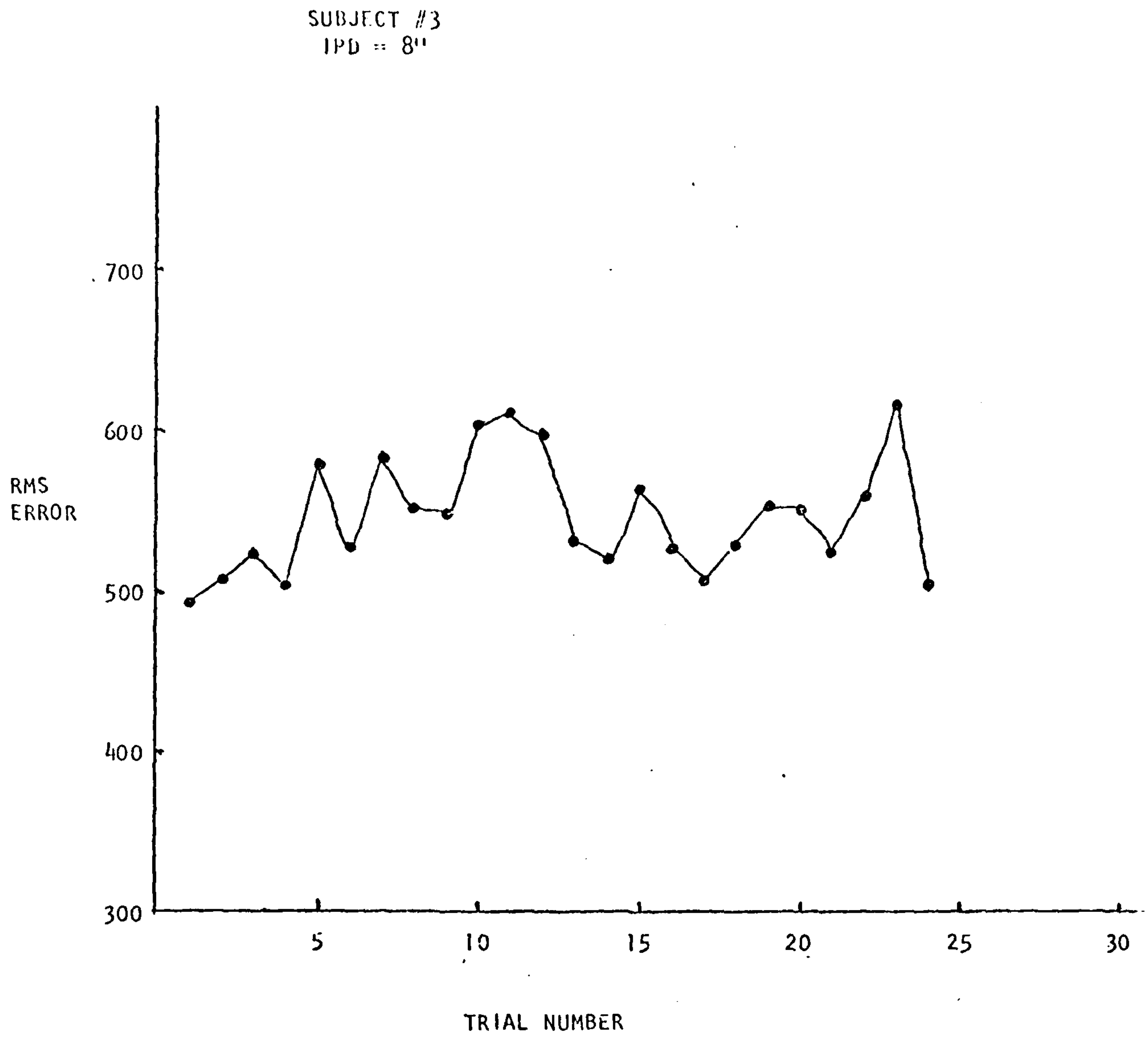

Figure 5b. Variations in rms error at given IPD

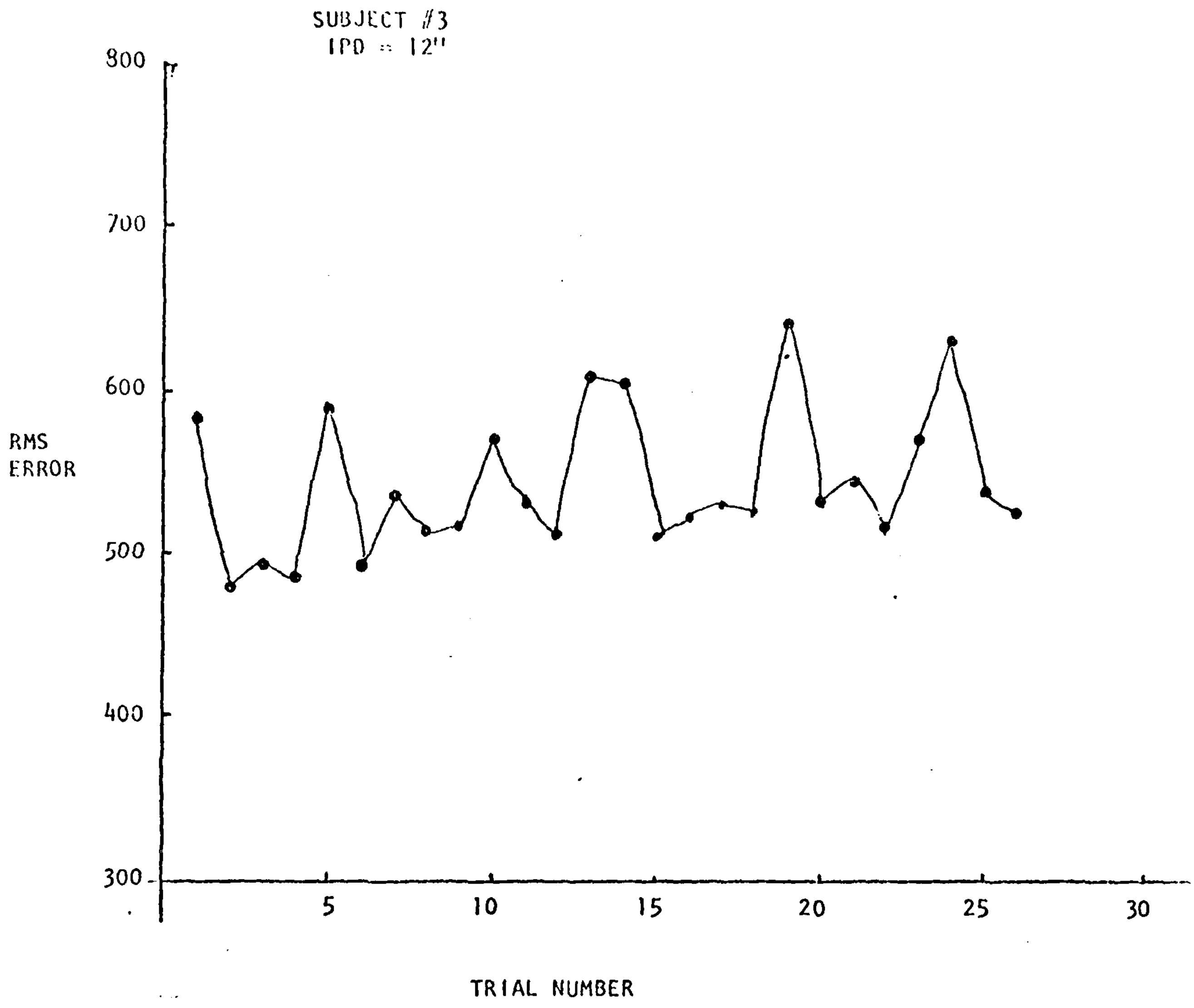

Figure 5c. Variations in rms error at given IPD

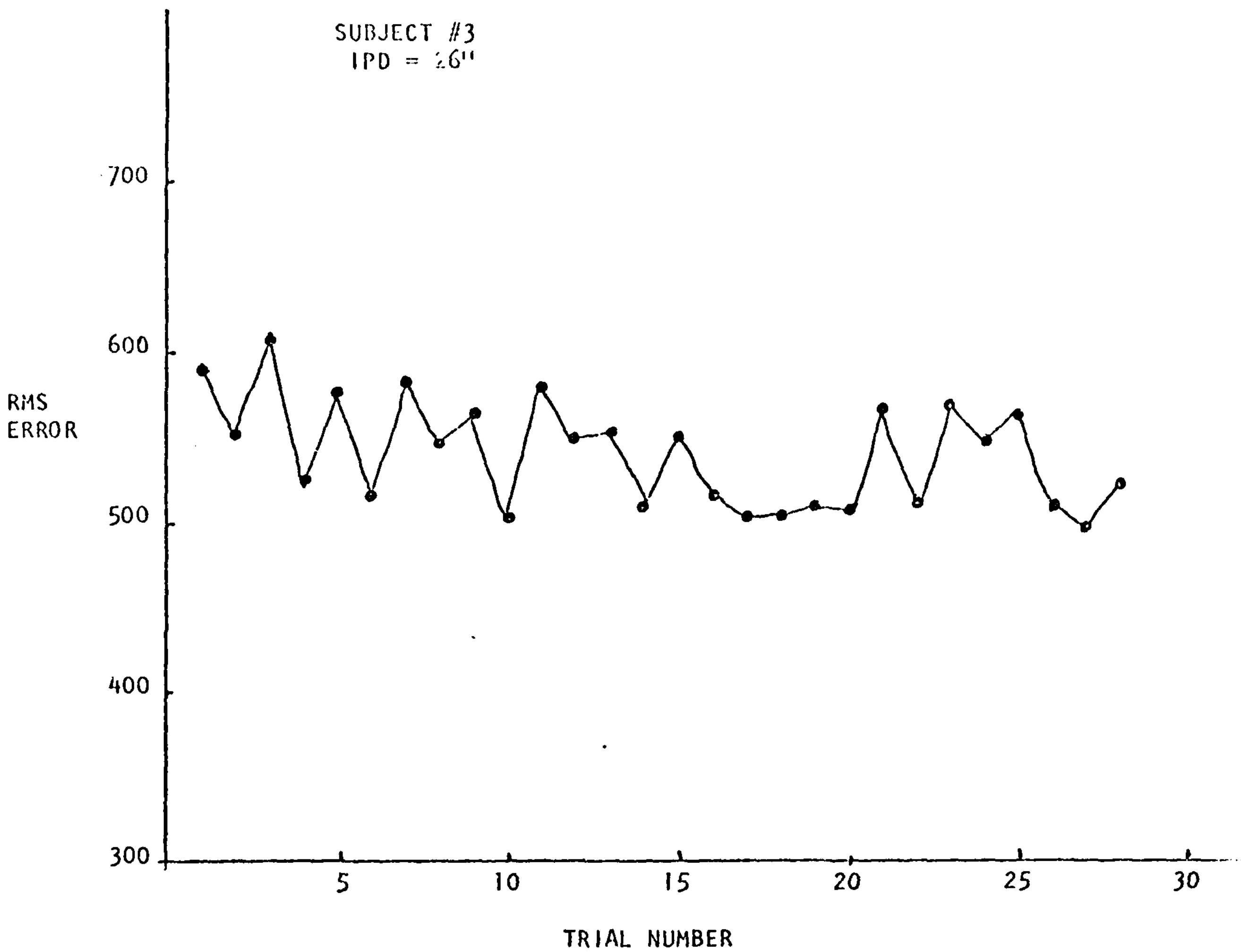

Figure 5d. Variations in rms error at given IPD

DISCUSSION

The findings from this study show that the introduction of stereovision in a tracking task can significantly improve performance when only monocular depth cues are available. Furthermore, the improvements in performance increase as separation of the eyes is increased. This improved performance is expressed as a generally tighter target tracking ability and more consistent performance from trial to trial. Finally the effects of peripheral objects can apparently be ignored and may not influence tracking ability under these test conditions.

Superior performance when stereo information is available as opposed to only monocular depth cues has been reported using stereo threshold measurements. Zamarin[7] in an extensive study of an enhanced disparity and stereo threshold showed continued improvement in stereo judgements as IPD increased. However, the improvement increased at a decreasing rate after a 12 inch IPD. The results from this study do not contradict these findings but extend their applicability to tracking and manual control. Tracking performance improved as separation increased to the limit in this experiment as would be predicted based on Zaramin's results of threshold measurements. However, a continual improvement in tracking ability at 8 and 12 inch separations was not found in the present study. Possibly the small subject population contrasted with Zamarin's 20 subjects can account for this discrepancy. Alternatively, this difference may reflect the differences in the tasks performed in each subject population.

The significant difference in performance with stereo viewing conditions versus without was probably a result of misjudgements in target direction, and/or reaction time rather than not detecting target movement. If target motion was not detected and these subjects not operate the joystick the RMS error would be that of the pseudo-random target disturbance (t_o=657). However, the monocular viewing data was in excess of this value in all subjects. Thus it seems likely that subject did detect target movement, perhaps using luminance or size changes, but incorrectly judged the direction of its movement creating more error rather than less. Also, increases in reaction times to target movements due to ambiguous monocular cues, would have the subject correcting for a past target distance at an inappropriate time and thus increasing error rather than decreasing it. These two possibilities are intriguing and may deserve further exploration to understand each subject's contribution to poorer performance.

The effects of peripheral targets on the subjects perceived ability to track seem minimal although tracking without peripheral targets was not done. Nevertheless subjects report ignoring peripheral content and concentrating on the task. The extent to which subjects may ignore peripheral targets needs more attention in future investigations on enhanced disparity displays.

The fatigue reported by these subjects and their possible affects on performance should be more extensively investigated. The small pool of data shown in this report is not sufficient to address this as a problem. Enhanced stereo display may induce eye fatigue much quicker than normal. This fatigue may result in temporary or transient unocular suppression of retinal information. Such suppression may be sufficiently strong to cause subjects to lose stereovision temporarily and thus perform as if using a monocular display. Further work using realistic visual stimuli, perhaps in a simulator, would clarify the extent to which this condition occurs.

Finally, the reader is reminded that motion parallax was not one of the monocular cues permitted in these experiments. Under certain conditions this can provide a powerful depth cue. Future experiments should include motion parallax in enhanced stereopsis studies to define where and when this cue may be as useful as enhanced stereopsis.

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